Soil Quality Indicators

Soil Electrical Conductivity

Soil electrical conductivity (EC) measures the ability of soil water to carry electrical current. Electrical conductivity is an electrolytic process that takes place principally through water-filled pores. Cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, and NH_4^{+}) and anions (SO_4^{2-}, Cl^{-}, NO_3^{-}, and HCO_3^{-}) from salts dissolved in soil water carry electrical charges and conduct the electrical current. Consequently, the concentration of ions determines the EC of soils. In agriculture, EC has been used principally as a measure of soil salinity (table 1); however, in non-saline soils, EC can be an estimate of other soil properties, such as soil moisture and soil depth. EC is expressed in deciSiemens per meter (dS/m).

Factors Affecting

Inherent - Factors influencing the electrical conductivity of soils include the amount and type of soluble salts in solution, porosity, soil texture (especially clay content and mineralogy), soil moisture, and soil temperature. High levels of precipitation can flush soluble salts out of the soil and reduce EC. Conversely, in arid soils (with low levels of precipitation), soluble salts are more likely to accumulate in soil profiles resulting in high EC. Electrical conductivity decreases sharply when the temperature of soil water is below the freezing point (EC decreases about 2.2% per degree centigrade due to increased viscosity of water and decreased mobility of ions). In general, EC increases as clay content increases. Soils with clay dominated by high cation-exchange capacity (CEC) clay minerals (e.g., smectite) have higher EC than those with clay dominated by low CEC clay minerals (e.g., kaolinite). Arid soils with high content of soluble salt and exchangeable sodium generally exhibit extremely high EC. In soils where the water table is high and saline, water will rise by capillarity and increase salt concentration and EC in the soil surface layers.

It is generally accepted that the higher the porosity (the higher the soil moisture content), the greater the ability of soil to conduct electrical currents; that is, other properties being similar, the wetter the soil the higher the EC. Soil parent materials contribute to EC variability. Granites have lower EC than marine shales and clayey lacustrine deposits have higher EC than sandy outwash or alluvial deposits. Saline (ECe ≥ 4 dS/m) and sodic (sodium absorption ratio ≥ 13) soils are characterized by high EC. Scientific literature reported a relationship between EC values measured with commercial sensors and depths to claypan, bedrock, and fragipan. Microtopographic depressions in agricultural fields typically are wetter and accumulate organic matter and nutrients and therefore have higher EC than surrounding higher lying, better drained areas.

Dynamic - Mineral soils enriched in organic matter, or with chemical fertilizers (e.g., NH_4OH) have higher CEC than non-enriched soils, because OM improves soil water holding capacity, and synthetic fertilizers augment salt content. Continuous application of municipal wastes on soil can increase soil EC in some cases. Electrical conductivity has been used to infer the relative concentration, extent, and movement of animal wastes in soils. Because of its sensitivity to soluble salts, EC is an effective measure for assessing the contamination of surface and ground water. Although EC does not provide a direct measurement of specific ions or compounds, it has been correlated with concentrations of potassium, sodium, chloride, sulfate, ammonia, and nitrate in soils. Poor water infiltration can lead to poor drainage, waterlogging, and increased EC.

Relationship to Soil Function

Soil EC does not directly affect plant growth but has been used as an indirect indicator of the amount of nutrients available for plant uptake and salinity levels. EC has been used as a surrogate measure of salt concentration, organic

Table 1. Classes of salinity and EC (1 dS/m = 1 mmhos/cm; adapted from NRCS Soil Survey Handbook)

EC (dS/m)	Salinity Class
0 < 2	Non-saline
2 < 4	Very slightly saline
4 < 8	Slightly saline
8 < 16	Moderately saline
≥ 16	Strongly saline

matter, cation-exchange capacity, soil texture, soil thickness, nutrients (e.g., nitrate), water-holding capacity, and drainage conditions. In site-specific management and high-intensity soil surveys, EC is used to partition units of management, differentiate soil types, and predict soil fertility and crop yields. For example, farmers can use EC maps to apply different management strategies (e.g., N fertilizers) to sections of a field that have different types of soil. In some management units, high EC has been associated with high levels of nitrate and other selected soil nutrients (P, K, Ca, Mg, Mn, Zn, and Cu).
Most microorganisms are sensitive to salt (high EC). Actinomycetes and fungi are less sensitive than bacteria, except for halophyte (salt-tolerant) bacteria. Microbial processes, including respiration and nitrification, decline as EC increases (table 2).

Problems with Poor Soil EC Levels

High EC can serve as an indication of salinity (EC > 4 dS/m) problems, which impede crop growth (inability to absorb water even when present) and microbial activity (tables 2 and 3). Soils with high EC resulting from a high concentration of sodium generally have poor structure and drainage, and sodium becomes toxic to plants.

Improving Soil EC

Effective irrigation practices, which wash soluble salts out of soil and beyond the rooting depth, can decrease EC. Excessive irrigation and waterlogging should be avoided since a rising water table may bring soluble salts into the root zone. In arid climates, plant residue and mulch help soils to remain wetter and thus allow seasonal precipitation and irrigation to be more effective in leaching salts from the surface. To avoid the adverse effects of high EC (salinity) in irrigation water, the leaching requirement must be calculated for each crop. Leaching requirement is the fraction of water needed to flush excessive salt below the root zone, that is, the amount of additional water required to maintain a target salinity level. Adding organic matter, such as manure and compost, increases EC by adding cations and anions and improving the water-holding capacity. In some cases, a combination of irrigation and drainage is necessary to lower salt concentration and EC. An EC water (ECw) ≤ 0.75 dS/m is considered good for irrigation water. Beyond this value, leaching or a combination of leaching and drainage will be necessary if the water is used.

Table 2. Influence of soil EC on microbial process in soils amended with NaCl or nitrate (adapted from Smith and Doran, 1996)

Microbial process	Salt added	EC Range (dS/m)	Relative Decrease (%)	Threshold EC (1:1)
Respiration	NaCl	0.7 - 2.8	17 - 47	0.7
Decomposition	NaCl + alfalfa	0.7 - 2.9	2 - 25	0.7
Nitrification	soil + alfalfa	0.7 - 2.9	10 - 37	0.7
Denitrification	NO_3-N	1 - 1.8	32 - 88	1

Measuring Soil EC

The EC pocket meter is used to take measurements in the field. The method is described in the Soil Quality Test Kit Guide. Always calibrate the EC meter before use.

The pocket meter can be augmented by a probe that is placed directly into the soil to measure subsoil EC and NO_3^- and make other estimates. NRCS soil scientists and agronomists use electromagnetic induction meters, not pocket EC meters, to map spatial variability of EC and associated soil properties at field scales. Special sensors are used for EC mapping for precision agriculture.

Time needed: 10 minutes

References:
Corwin DL and SM Lesch. 2005. Apparent soil electrical conductivity measurements in agriculture. Computers and Electronics in Agriculture 46:11-43.

Smith JL and JW Doran. 1996. Measurement and use of pH and electrical conductivity for soil quality analysis. In Methods for assessing soil quality. Soil Science Society of America Special Publication 49: 169-185.

Doolittle JA, KA Suddeth, NR Kitchen, and SJ Indorante. 1994. Estimating depths to claypans using electromagnetic induction methods.

Table 3. Salt tolerance of crops and yield decrease beyond EC threshold (adapted from Smith and Doran, 1996)

Crop species	Threshold EC 1:1 (dS/m)*	Percent yield decrease per unit EC beyond threshold EC
Alfalfa	1.1 - 1.4	7.3
Barley	4.5 - 5.7	5.0
Cotton	4.3 - 5.5	5.2
Peanut	1.4 - 1.8	29
Potato	1.0 - 1.2	12
Rice	1.7 - 2.1	12
Soybean	2.8 - 3.6	20
Tomato	1.4 - 1.8	9.9
Wheat	3.9 - 5.0	7.1

* *Electrical conductivity of a 1:1 soil/water mixture relative to that of a saturated paste extract*